Lubrication

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the Selection and Use of Lubricants

THIS ISSUE

The Relation of Carbon
Residue to Lubricating
Performance

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Carbon

AND ITS EFFECT UPON MACHINE OPERATION

THERE is a certain element of danger implied by the word carbon. To those who have to do with lubrication it spells the possibility of interference with flow of oil to parts to be lubricated.

It is justifiable to regard carbon as a potential source of danger, but we must remember that for this to be true carbon must be present in its residual, or more or less solidified form.

When we realize that carbon is one of the major constituents of all petroleum products, and that in compound with hydrogen it forms a wide variety of so-called hydrocarbons which have decided lubricating value, a study of how it may be brought into residual form and the detriments which this latter may give rise to, will be of definite interest.

We have, therefore, devoted this issue of LUBRICATION to such a study, to give a more complete idea as to the chemical nature of lubricants, the methods of testing to determine the amount of objectionable carbon residue to be expected, and the several phases of machine operation which may be affected thereby.

If our discussion serves to broaden the aspect of the users of lubricants as to the chemistry of lubrication and the part played by the element carbon, the purpose of this article will be attained.

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The Relation of Carbon Residue to Lubricating Performance

IN the operation of certain types of machinery the development of carbon residue deposits from lubricating oils may seriously impair power development and result in a general reduction in machine efficiency. This will be especially true in connection with the internal combustion engine, the air compressor, and, in certain instances, the steam engine.

On the other hand, there are a great many other phases of industry wherein operating temperatures at the bearing elements may become so high as to cause breakdown of the lubricants and deposition of more or less carbon residue, which can normally be expected to remain within the bearings, oil grooves or other parts of the lubricating system. Typical instances of where this may occur will be in the operation of such machinery as the textile calender, the dryers in the paper industry and, in fact, any other machinery wherein steam or hot water connections are located so close to the bearings as to bring about abnormal rises in temperature or where kiln treating or metal working may be involved.

As a result of the fact that carbon residue may therefore be expected to develop into a decided detriment, in connection with the maintenance of effective lubrication, it is felt that a study of this, and the manner in which carbon occurs in all petroleum lubricants, should be of interest.

Carbon is an inherent component of all such lubricating oils, for petroleum products are made up of a complex arrangement of hydrocarbons. It is not intended to go too deeply into the chemistry involved, for, dependent upon the degree of refinement and the accuracy of distillation and fractionating, the relative amount of these hydrocarbon constituents may vary widely. It is enough to say, however, that whatever the chemical structure the element carbon will be present.

In a realization of this fact, every effort has been devoted by the petroleum industry to produce lubricating oils which will retain their original hydrocarbon formation as nearly as possible in actual operation. It is impossible, however, to completely prevent breakdown of certain of these hydrocarbon constituents into their basic elements, especially when certain types of lubricants are subjected to temperatures sufficiently high to bring about a certain amount of vaporization in the oil.

Fortunately, however, it is practicable to develop in the laboratory a measure of the approximate amount of carbon residue which may be expected from any particular grade of lubricating oil in actual operation. Some extremely interesting investigation along this line has been carried out by Marley, Livingstone and Gruse, of the Mellon Institute of Industrial Research, in connection with automotive engine lubrication. The most recent work of the latter* has shown: "First, that the carbon depositing tendencies of automobile oils can be predicted approximately from the carbon residue test of these oils; and second, that the

*In "Carbon Deposits from Lubricating Oils," presented before the Division of Petroleum Chemistry at the 78th meeting of the American Chem. Society, Minneapolis, 1929. See pp. 904-8 Industrial and Engineering Chemistry, Oct. 1929.

carbon residue test is significant probably because it is a rough indication of the volatility, at flame temperature, of the oils."

CHEMICAL CONSTITUENTS

The manner in which carbon occurs in petroleum products will be of decided interest
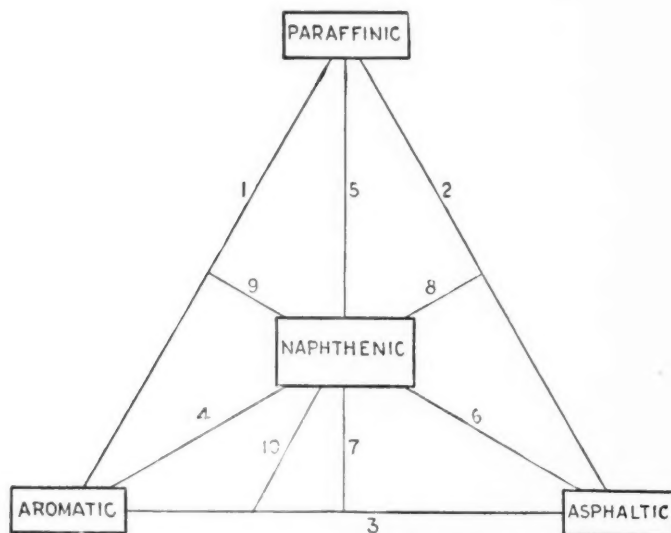
Courtesy of W. A. Gruse and McGraw-Hill Book Co.

Fig. 1—Composition Diagram, showing the relation of constituents in various possible crude oils. Note the position of the naphthenes. In the opinion of Gruse—"They are regarded as of most importance, occurring largely in all oils" . . . "In the term 'Naphthene' is included not only the ordinary monocyclic hydrocarbons, but also higher saturated polycyclic substances which are believed to make up the high-boiling portions of practically all petroleums."

in connection with this discussion of carbon residue development.

In the average petroleum product, according to Gruse, there will be from 83% to 87% of carbon, with 11% to 14% of hydrogen. The balance of any such product will include more or less oxygen, nitrogen and sulfur, with the latter usually predominating, though in relatively small proportion.

In refinery practice crude oils are normally grouped into two broad classifications, according to their base, i.e., paraffin or naphthenic. From a chemical point of view, however, we must go a step beyond and include the aromatic and asphaltic compounds.

Gruse has illustrated this by the accompanying diagram.* He states that "The four main constituents can be placed on a diagram, as shown in Fig. 1, and mixtures of the constituents can be expressed by lines joining the constituents. For example: line 1 describes a mixture of paraffin and aromatics; line 2, a mixture of paraffins and asphalts; line 3, a mixture of aromatics and asphalts. Lines 4, 5 and 6 represent mixtures of naphthenes with

*"Petroleum and Its Products," p. 4, 5 by W. A. Gruse, Ph.D.

aromatics, paraffins and asphalts, respectively. Line 7 represents a mixture of naphthenes with aromatics and asphaltic compounds, and lines 8 and 9 have a similar obvious significance. Line 10 represents, as does line 7, a mixture of naphthenes with aromatics and asphalts, but a mixture in which the aromatics predominate over the asphaltic constituents."

The extent to which these various constituents will exist in any crude will depend upon the geological formation from which the oil originated.

In view of the residual nature of the average asphaltic hydrocarbons, and especially since the naphthenic components occur very largely in all oils, the chemist, in studying the several types of hydrocarbons prior to refinement, has arranged these under the terms: paraffins, naphthenes, aromatics and unsaturated compounds.

The amount, or percentage, of carbon residue which may be produced from any petroleum product will depend upon the boiling point, constitution and composition of the hydrocarbons present.

It is important to remember in this regard that increase in boiling point, as well as increase in viscosity, assuming that the same degree of refinement has been made, will result in an increase in carbon residue content. In other words, a lubricant of 80 seconds Saybolt viscosity, at 210 degrees Fahr., will normally show a higher carbon residue content than a product of say 50 seconds viscosity at the same temperature, provided of course that they have both been subjected to similar processes of refinement.

METHODS OF TEST

The determination of the carbon residue content for any lubricant can be accurately made according to the nature of the latter by the Conradson Method, as adopted by the American Society for Testing Materials in the United States, or the Ramsbottom Method, as approved by the Institution of Petroleum Technologists in England.

As a brief introduction to these methods, it is well to state that each involves the external heating of a measured quantity of the oil within suitable apparatus wherein all vapors are driven off, until complete distillation has been accomplished. The resultant residue in either the coking bulb of the Ramsbottom Method, or the crucible of the Conradson device, will be the carbon residue content of the original

sample of oil. By careful weighing it can be expressed on a percentage basis in relation to the oil under test.

The above is only a generalized statement of how the results are attained. It will be of interest, therefore, to give the detailed construction and the method of procedure in connection with both the Conradson and Ramsbottom tests.

The Conradson Method

According to Committee D-2, of the A.S.T.M., (under A.S.T.M. Designation: D 189-28) this involves a porcelain crucible (a), located within (b) a Skidmore iron crucible. Both are in turn contained within a spun sheet-iron crucible, with a suitable cover. (See Fig. 2.)

In the bottom of the latter is placed a layer of dry sand, enough to bring the Skidmore crucible with a cover on it nearly to the top of the sheet-iron crucible. Below this crucible is a wire triangle with an opening small enough to allow it to serve as a support; (e) is a circular sheet-iron hood, provided with a chimney at the top as shown; (f) is an asbestos block or hollowed sheet metal box within which the arrangement of crucibles is located; (g) is a Meker type gas burner. More complete details on the above apparatus, with sizes and capacities, are shown on pages 65 to 68 of the report of Committee D-2 on Petroleum Products and Lubricants, 1929.

The procedure in the determination of carbon residue as recorded by the A.S.T.M., is as follows:

"Place two glass beads about 0.1 in. in diameter in, and include them in the weight of, the tared porcelain or silica crucible in which is accurately weighed 10 g. of the oil to be tested, free from moisture or other suspended matter. Place this crucible in the center of the Skidmore crucible. Level the sand in the large sheet-iron crucible and set the Skidmore crucible on it in the exact center of the iron crucible. Apply covers to both the Skidmore and the iron crucible, the one to the latter fitting loosely to allow free exit to the vapors as formed.

"On a suitable stand, place the bare nichrome wire triangle and on it the asbestos block or hollow sheet-metal box. Next, center the sheet-iron crucible in the block with its bottom resting on top of the triangle, and cover the whole with the sheet iron hood in order to distribute the heat uniformly during the process.

"Apply heat with a high strong flame from the Meker type gas burner so that the pre-ignition period will be 10 minutes $\pm$ 1½ minutes (a shorter time may start the distillation so rapidly as to cause foaming or too high a flame). When smoke appears above the chimney, immediately move or tilt the burner so that the gas flame plays on the sides of the crucible for the purpose of igniting the vapors. Then remove the heat temporarily, and before replacing adjust by screwing down the pinch-cock on the gas tubing so that the ignited
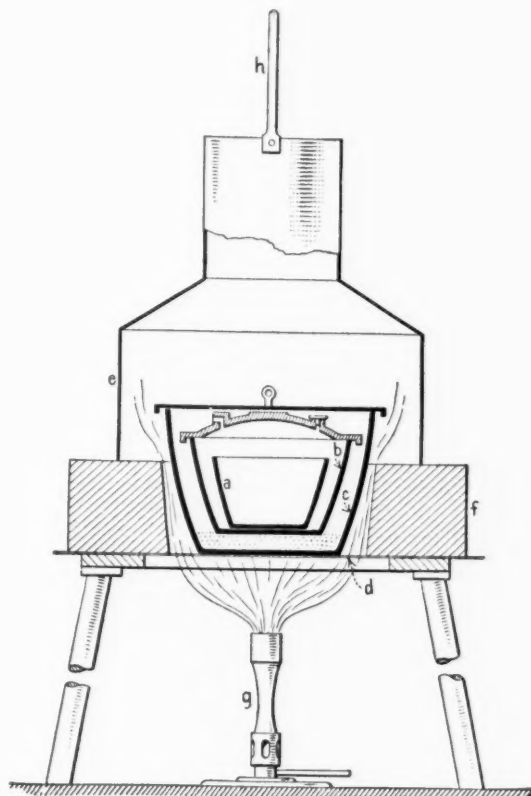

Fig. 2—Showing apparatus for determining carbon residue, as adopted by the American Society for Testing Materials. (a) indicates the porcelain crucible, (b) the Skidmore crucible, (c) the spun sheet iron crucible, with cover, (d) the bare nichrome wire triangle, (e) the circular sheet iron hood, (f) the asbestos block or hollow sheet metal box, and (g) the Meker type burner.

vapors burn uniformly with the flame above the chimney but not above the wire bridge. Heat may be increased, if necessary, when the flame does not show above the chimney.

"When the vapors cease to burn and no further blue smoke can be observed, readjust the burner and hold the heat as at the beginning so as to make the bottom and lower part of the sheet iron crucible a cherry red and maintain for exactly 7 minutes. The total period of heating shall be 30 minutes $\pm$ 2 minutes. There should be no difficulty in carrying out the test exactly as directed with the gas burner of the type named, using city gas (about 550 B.t.u.) with the top of the burner about 2 inches below the bottom of the crucible. The time periods shall be observed with whatever burner and gas is used.

"Remove the burner and allow the apparatus to cool until no smoke appears, and then remove the cover of the Skidmore crucible (about 15 minutes). Remove the porcelain or silica crucible with heated tongs, place in the desiccator, cool and weigh. Calculate the percentage of carbon residue on the original sample."

Tolerances

"Weights of oil sample shall be accurate to within 5 mg. Tests shall be run in duplicate and repeated if necessary until the percentages of carbon residue differ by not more than 10% from an average."

The Ramsbottom Method

In contrast with the Conradson method, as adopted by the A. S. T. M. in the United States, discussion of the Ramsbottom method, which has been taken as the standard method by the Institution of Petroleum Technologists, in England, will be of interest. This latter has been extensively discussed by C. I. Kelly[*] before the Institution, and recorded in the Journal of the above association in October, 1929 (pp. 495-515). The apparatus involved and procedure are as follows:

Apparatus

"The sheath shall be an iron tube, the closed end of which shall be flat, 3 inches in length,

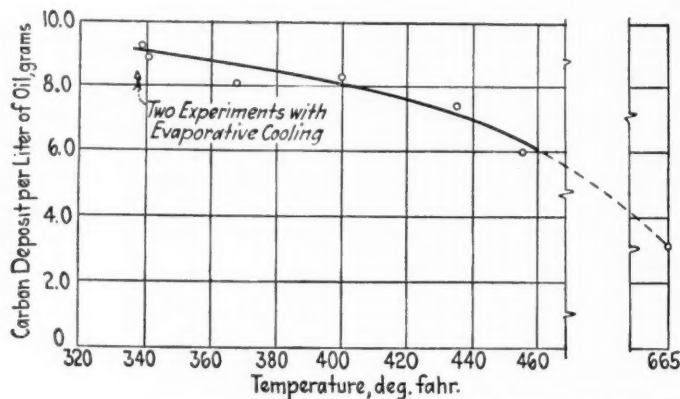Courtesy of Society of Automotive Engineers

Fig. 3—Diagram prepared by Marley, Livingstone and Gruse for their article on "Influence of Temperature, Fuel and Oil on Carbon Deposition," appearing in the Journal of the Society of Automotive Engineers for June, 1926. This curve is to show carbon values, plotted against head temperatures. According to the authors—"Note drop in grams of deposit per liter of oil consumed as the cylinder-head temperature was increased. Two experiments with evaporative-cooling gave low operating temperature and approximately corresponding carbon value, as indicated by the triangle."

1 inch in internal diameter, and approximately $\frac{1}{16}$ inch thickness of wall.

"The coking bulb shall be blown from glass tubing of 1 mm. wall thickness and shall be a sliding fit in the iron sheath. One end shall be

*Lubricating Oils: Carbon Residue Estimation. The Ramsbottom Method.

rounded and the other drawn out to a capillary of 1.5 mm. internal diameter and 9.5 mm. in length. The distance from the base to the shoulder of the bulb shall be 38 mm. and the overall length from the base to the tip of the capillary shall be 57 mm.

Method

"The sheath shall be maintained at a constant temperature of 1020 degrees Fahr. (550 degrees Cent.) in a bath containing such a quantity of molten metal (lead) that the bottom of the sheath shall be 1 inch from the bottom of the bath and the sheath shall project not more than $\frac{1}{8}$ inch above the surface of the molten metal. The temperature shall be controlled by a reliable pyrometer, accurate to $\pm$ 5 degrees Cent., which shall be placed in the bath as near as possible alongside the sheath, the end being 1 inch from the bath bottom. It is desirable that the pyrometer stem be fitted with a quartz sheath as protection against the deteriorating effect of the molten metal, and when using the type of pyrometer where the cold junction is at room temperature a zero adjustment should be made with one lead detached, it being advisable to check the zero before each experiment. The recording instrument should be protected from the heat radiated from the bath.

"A clean bulb shall be weighed and 3.75 to 4.25 grams of the oil introduced, the bulb being conveniently filled by inserting a glass capillary, suitably bent, and applying suction while the end of the bulb is immersed in the oil.

"The bulb containing the oil shall be placed in the sheath and allowed to remain for ten minutes after fuming has ceased. The bulb shall be re-weighed when cool, care being taken to remove any small particles of adhering metal before weighing.

"The bulbs may be cleaned after use by heating in a mixture of concentrated sulphuric acid and potassium hydrogen sulphate, care being taken to remove all traces of acid when finally washing with distilled water."

Temperature Control a Factor

Testing for carbon residue requires very accurate control of the method of heating. The American Society for Testing Materials has, in fact, indicated that this is in all probability the most important factor in the making of such a test. The report of Sub-Committee 23, in 1927, has summarized this to the effect that heat must not only be applied in a positively controlled manner, but also over a definite period of time.

The Hot Plate Test

A more relative means of determining the extent to which a lubricant will develop carbon residue involves the hot plate test, so familiar to the motorist. As a rule it is practicable as a qualitative test only.

This involves the use of a simple domestic type of electrically heated hot plate. By means of a suitable voltage-varying plug the ultimate temperature to which such a plate will be heated can be controlled. This is of especial value where lubricants to meet varying high temperature conditions are concerned.

The method of test is to bring such a plate to the requisite temperature and then deposit a drop of the proposed oil thereupon. The resultant smudge or carbon residue which will remain after vaporization of the lighter, more volatile fractions which compose the lubricant, will indicate the relative degree to which such a product will probably develop carbonaceous deposits in actual service.

It must be understood, however, that this test is purely relative. Furthermore, erroneous conclusions may be drawn if any attempt is made to compare oils of different viscosities.

Influence of Oil Viscosity

Extensive research on both the Conradson and Ramsbottom methods has developed a difference of opinion as to the oil viscosity range to which they may be adaptable. This is especially true in regard to the Ramsbottom method, it being normally assumed that by the Conradson method both lubricating oils and residual fuel oils of any viscosity can be tested.

In regard to the Ramsbottom method, however, the Institution of Petroleum Technologists,* in discussing the standard method for carbon residue (Conradson) on fuel oils (other than intermediate oils Class VI), states that "The use of the Ramsbottom method is not recommended for residue oils."

To test the validity of this statement, however, Kelly refers to a number of experiments

*Standard Methods of Testing Petroleum and Its Products, Second Edition, p. 90.

carried out on a heavy residual fuel oil, with a viscosity of several thousand seconds, Redwood, at 100 degrees Fahr. As a result of these experiments he says, "It appears, therefore, that the Ramsbottom Carbon Residue method is applicable to heavy residual fuel oils, provided that not more than 2 grams of dry oil are employed."

The Conradson method, however, all things being equal, is apparently a more adaptable method for normal laboratory practice, due to the greater rapidity with which tests can be made, and also the lower initial cost of the device, etc.

On the other hand, according to certain authorities, variables such as temperature, for example, cannot be as easily controlled throughout the test as is practicable when using the Ramsbottom method.
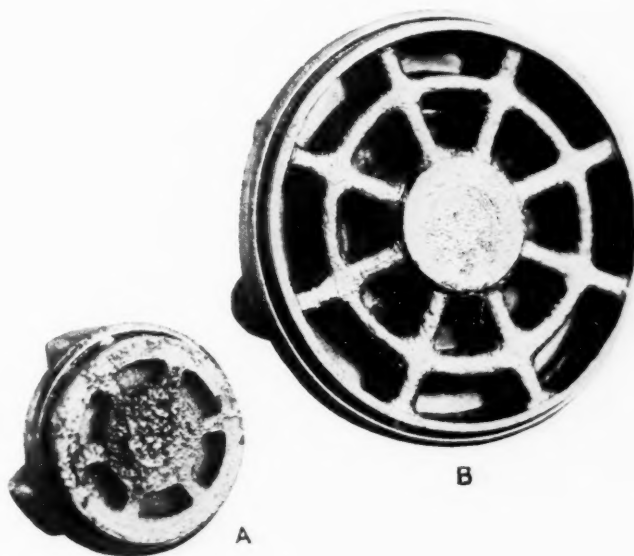

Fig. 4—Showing the contrast in carbon accumulation on air compressor valves run for approximately the same time under similar conditions of operation. At (a) is shown a valve from a compressor wherein too much oil of improper quality was used. At (b) is shown a valve from a compressor lubricated with a suitable grade of oil, applied in the correct amount. It is obvious that carbon accumulation, as shown on valve (a), may easily result in faulty operation of the valve and lack of efficiency in the entire machine.

Obviously each method may, therefore, have advantages and disadvantages. It is not the purpose of this article to indicate any preference, the purpose being rather to give an insight into the operation of each in connection with the ultimate determination of carbonaceous residues which may prove detrimental to effective lubrication.

Relation of Operating Conditions to Carbon Residue Developments

AUTOMOTIVE SERVICE

The relation of automotive operating conditions, as brought out by actual road tests, to the development of carbon residues in lubricating oils has been studied by Marley Livingstone and Gruse in their experiments already mentioned. As a result of this work they have suggested that, "The fundamental property involved is the volatility at flame temperature (as prevailing in the combustion chamber) of the oil, and that the carbon residue test owes its significance to its being a rough measure of such volatility. As a matter of fact, the carbon residue test is probably dependent upon three main factors: (a) the amount of completely non-volatile, easily cracked asphaltic and similar material in the oil; (b) the proportion of hydrocarbon material which is non-volatile enough to stay behind and crack; (c) the character of this non-volatile residuum which will crack to more or less coke, depending on its composition."

In connection with the above, these investigators have concluded that "The carbon residue test is a fairly reliable index of carbon deposition in a poppet-valve engine, other conditions being rigidly the same. Of seventeen oils listed, fifteen give fair agreement with a straight-line relationship to carbon residue test. Its success is most conspicuous in evaluating paraffinic oils. The setting, in oil specifications, of reasonable upper limits for carbon residue values in the same viscosity class should protect the user from excessive carbon deposits, because a paraffinic oil of low carbon residue value must be very highly refined; a naphthenic oil, always of low carbon residue value, has an inherent tendency to low carbon deposit. In either case, the user will be protecting himself against abnormal carbon deposition."

Influence of Type of Engine

These investigators further state that, "The construction of the ports in a sleeve-valve engine is such that the carbon deposited is subject to erosion by the exhaust gases. A soft, fluffy carbon will not have much opportunity for accumulation. A heavy, sticky carbon, on the contrary, will build up in a very short time. Any amount of deposit will decrease appreciably the gas flow through the port and the deposit will augment itself rapidly. In other words, the process of deposition increases progressively, after the manner of a snowball rolling down hill."

They also bring out that a, "Factor in engine carbon deposits, which is not reflected in the carbon residue test, is the character of the coke formed on cracking. A dry, powdery form, free of binder, is desirable, since mechanical influence inside the engine can easily remove it. This is brought out forcibly by the present work with sleeve-valve engines. Such loose deposits seem also to be an inherent characteristic of naphthenic oils."

AIR COMPRESSOR SERVICE

In air compressor service deposits of carbon on the valves or in the discharge lines are to a certain extent caused by decomposition of the oil, due to the fact that mineral lubricating oils, regardless of their base or nature, will decompose to volatile products and carbon residue when subjected to heated air under pressure. The extent of this decomposition, of course, depends on the length of time the oil is exposed to such heat. It will also follow that the oil which remains in the compressor cylinder or on the discharge valves the longest will form the greatest amount of carbon.

On the other hand, analysis of numerous so-called carbon deposits have proven them to consist of quite as much dirt as carbon, the whole being held together by gummy matter from decomposed oil. For this reason an oil having a wide range of distillation, high end point, or too great a viscosity is objectionable, inasmuch as instead of vaporizing cleanly it breaks down as has been mentioned above, becoming sticky and collecting dirt brought in by the air. The slower the breaking down process, or the greater the volume of oil involved, the greater will be the ultimate amount of carbon residue.

Carbon may be formed in air compressor cylinders in a hard mass, or it may be produced in the shape of dust, in which case the majority will pass out with the air. Where this latter occurs, however, such residues will often collect in pockets, elbows or on sharp edges and become mixed with dirt taken in by the air as well as with oil which has been vaporized in the cylinder, and later condensed at these points.

If deposited in the cylinder, carbon, being a poor conductor, may become heated considerably above the temperature of the cylinder walls; but whether it can become sufficiently heated to ignite or not is still a matter of dispute. However that may be, carbon is always a nuisance, and many times it accumulates on the valves and valve seats and is packed firmly

into the ends of the cylinders, causing the valves to leak and sometimes resulting in the breaking of the valves and scoring of the cylinders. Cases have been found where carbon deposits have collected in the valve passages and bends of piping to such an extent as to restrict the opening through which the compressed air had to pass. When once started, such formations continue to build up, so narrowing the passages that pressures may be produced capable of eventually causing an explosion.

The degree of refinement of an oil will be largely indicative of its carbon forming tendencies. Filtered oils will often show less tendency to break down to form carbon residue, or develop gummy matter. This latter is extremely important, for such gummy matter will absorb dust or dirt from the air and tend to increase the amount of residue. Furthermore, any such direct carbon that may be formed through excessive use of highly refined oils of the proper base, is of a light, fluffy nature. Any oil, however, will accumulate dust if the air is dirty.

The Use of Fixed Oil Compounds or Blended Oils

Whether or not the use of fixed oils of animal or vegetable matter such as lard oil, etc., in compound with mineral products, is advantageous for air cylinder lubrication is a subject of frequent discussion today. Where moisture is present in the air to a sufficient extent to cause appreciable precipitation of water, or if it is impossible to completely dry the air prior to its entry into the compressor (especially where higher pressures are involved), certain authorities deem it advisable to add a small amount of compound to the mineral compressor oil, or use a specially prepared product instead of increasing the rate of oil feed, in order to eliminate the possibility of dry pistons and cylinders, with subsequent loss of compression and rusting when the machine is shut down. This is especially applicable to some types of vertical and Diesel engine compressors. The ill-effects of possibly a moderate amount of increased carbonization are overlooked by some operators if by compounding their lubricating oils they can be assured of relatively satisfactory lubrication.

Others, however, regard the use of fixed oil compounds as a detriment, due to the fact that they are claimed to decompose slowly, especially if the mineral constituent is a blended or mixed base product. Fixed oils in fact are not subject to distillation under average conditions; instead, when exposed to higher temperatures they will tend to break down or decompose, developing a considerable amount of tarry or gummy residue.

Method of Air Cylinder Lubrication

Granted that the oil to be used for air cylinder lubrication satisfies the generally accepted requirements, it is safe to state that the possibility of future difficulties due to carbon formation will depend upon the method of feeding the oil and the quantity supplied. In fact, many authorities feel that this entire matter of efficient air compressor cylinder lubrication hinges upon the amount of oil used. Any excess supplied over that actually required will involve one of two alternatives:

(a) That the oil will either be consumed by vaporization and breaking down in the compressor with the formation of a certain amount of direct carbon, or

(b) That it will be carried over with the air to subsequently collect in the intercooler or in pockets elsewhere in the system.

As is the case in steam cylinder lubrication, the oil will function best where it is completely atomized prior to being delivered to the cylinder. To effect such atomization in small and medium-sized compressors, the oil is often introduced at or above the point of air intake, the inrush of air carrying the atomized particles or spray of oil to all parts requiring lubrication. On account of the lesser amount of oil involved, the lubricator can, in such cases, be located fairly near the intake as atomization is effected in a shorter distance of travel than where steam cylinders are involved.

Air, however, does not carry oil particles as readily as does steam. Horizontal compressors, therefore, may not receive sufficient oil at the uppermost parts of the piston and cylinder to insure satisfactory lubrication unless, of course, the oil feed is increased above the usual theoretical requirements. This is inadvisable, since the bottom parts of the cylinder, being probably over-lubricated, will lead to the collections of oil in pockets, with ultimate carbonization or even the possibility of explosion.

In such cases the better procedure is to feed the oil directly to the sliding surfaces by means of sight feed drip oilers or force feed lubricators. This, in fact, is customary practice on all large installations. Oil introduced in this manner is distributed to the cylinder walls by the wiping action of the piston.

Automatic lubrication by means of force feed lubricators whereby the flow of oil to each part of the cylinder can be regulated is perhaps the most efficient and economical method available. By its use, the possibility of over-feeding oil by any particular lubricator is reduced, for oil flow stops and starts with the compressor,

and the requisite lubricating and sealing film is attained. Force feed lubricators are not affected by variations in air pressure, and they will feed the oil continually in accordance with their adjustments and the speed of the compressor.

Of course, the different types of compressors will naturally involve certain variations in their lubrication; in fact, they may even require radical departure from what are normally called standard methods of lubrication. In general, however, the sight feed, hand regulated, or automatic force feed lubricator can be used; the system being planned according to the recommendations of the compressor builder, based on the design of the machine, its size, capacity, and the character of the valves employed.

Certain of the latter, such as flap and plate valves, ordinarily require no lubrication.
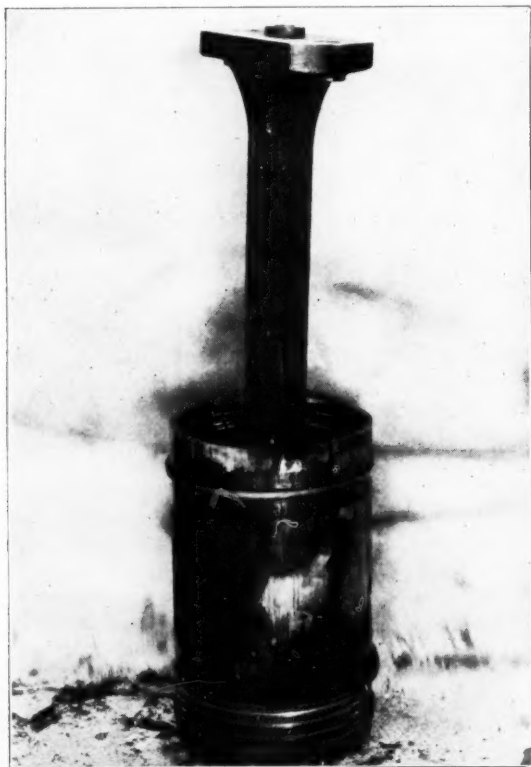

Fig. 5—Showing effect of carbon accumulation on the piston of a vertical gas engine. This piston was used on an engine operating 24 hours a day. A gradual loss in power required the removal of the piston and it was discovered that the rings were so badly gummed and stuck as to cause blow-by.

Others, such as grid, Corliss and poppet valves, require either direct application of oil, or will receive the requisite lubrication from the oil particles which are carried by the air. As a result, the operator or engineer should consult the builder of his machine, either when planning on lubricator installations, etc., or when he feels his lubrication is faulty. As often as not, the oil is perfectly adapted to his machine requirements, the methods of application being at fault.

Amount of Oil Required

To attempt to establish any hard and fast rule in regard to the theoretically proper amounts of oil that should be supplied to an air compressor cylinder is never advisable. Too many variables, such as the size of the compressor, its speed, and the condition of the piston and piston walls are involved. Essentially we must guard against over-lubrication, inasmuch as more trouble will be caused by the use of too much rather than too little oil.

It must be remembered that the oil will probably remain in an air compressor cylinder considerably longer than in the cylinders of either a steam or internal combustion engine, owing to the fact that there is little or no washing action or dilution of the oil film involved. As a consequence, very much less oil will be required per unit of cylinder surface over the same time interval.

It is a safe rule to use just enough oil to prevent frictional wear and to permit easy and free operation of all parts; more than this will lead to trouble. If the lubricant is unsuitable an excessive amount will be required to keep the pistons from groaning in the cylinders; in addition, the result of using an excessive amount of oil will be carbonization in the air passages, and particularly on the discharge valves. Sticking of these valves, with the passage of hot compressed air back into the compressor cylinder, is an indication of too much oil.

The discharge valves should therefore be examined regularly, and the aftercooler, receiver, or discharge pipes blown out. This will effectively remove any oil, water or sediment which may have accumulated. If upon removal, the discharge valves have a greasy appearance, enough oil is being fed to the cylinders; on the other hand, if the parts appear very oily or little pools of oil are found in compressor pockets, or in any of the air lines, oil is being fed in excess of that required.

There is a general rule to the effect that air compressors are sufficiently lubricated if one or two drops of the proper grade of oil are used for each 500 or 600 square feet of cylinder surface swept by the piston per minute. This rule, on the other hand, must be governed by the condition of the cylinders and the temperature and degree of compression.

The number of drops of oil which can be secured from a certain amount of any grade of oil varies with the viscosity, temperature, service conditions involved and the diameter and

shape of the lubricator orifice. Therefore, the number of drops secured per minute from an oil having a Saybolt viscosity of 200 seconds at 100 degrees Fahr. would differ from the number secured from an oil of 300 seconds viscosity. The type or design of lubricator; i.e., whether mechanical, force feed or hydrostatic, will also affect the number of drops obtained. As a result, it is not considered good practice to make a general recommendation of the number of drops per minute that should be used in air cylinders of various sizes, on account of the great variation in operating conditions that will be met with. In fact, two compressors of the same design, same size and built by the same manufacturer may be operating in a room under identical conditions, yet it will be practically impossible to secure the same fit of piston rings and valves and the same polished cylinder surfaces. Experience has shown that two such compressors may require a surprisingly different amount of oil for air cylinder lubrication.

In addition, the varying temperatures of the room will affect the feed of the lubricator, and while the operator may adjust the latter to give the same number of drops at different temperatures, with certain types of lubricators the difference in the size of the drops, and hence in the amount of oil fed to the cylinder, will be quite appreciable.

THE DIESEL ENGINE

Incomplete Combustion and Carbonization

In the operation of the Diesel engine the development of carbon residue will be brought about in very much the same manner as in the automotive type of internal combustion engine, in view of the comparatively high temperature to which both the lubricant and fuel are subjected. In the Diesel engine, however, there is more possibility of development of carbon residue from incomplete combustion of the fuel than in the automotive engine. The average grade of fuel oil, being very often partly or entirely of a residual nature, will have a higher percentage of certain hydrocarbon constituents, which will break down more readily and develop carbon residue.

Imperfect or incomplete combustion, therefore, requires detailed consideration, due not only to the extent to which it may develop carbon residues, but also the degree to which it may affect fuel economy in general.

Incomplete combustion is the result of low compression pressures, caused either mechanically or by leaky rings, excessive overloads or an improper mixture.

Where incomplete combustion is allowed to continue carbonization will practically always occur, especially on the piston head and in all probability around the rings. Therefore, carbonization is often the cause of faulty valve action and stuck piston rings. In turn this latter occurrence will cause compression losses.

In consequence a complete cycle of inefficiency may result. Where rings are stuck in their grooves they must be loosened as soon as possible. Oftentimes kerosene or a lye-water mixture will serve this purpose, cutting the gummy matter effectively, in case merely scraping away the deposits is not sufficient.

Sludge Formation

In connection with the performance of lubricating oils in Diesel engine service, it is interesting to note that the development of sludge may be taken as a qualitative indication of the formation of carbon residue, for according to Flowers and Dietrich* "The sludge that separates from Diesel engine lubricating oil is mainly carbonaceous matter."

This is interesting to note in that, with a knowledge of the rate of sludge separation, which can be measured by means of a centrifugal purifier, the approximate rate of carbon residue development can be judged during actual operation. In their experiments these investigators found that after an engine has been run-in, the carbonaceous sludge can be kept within 0.5 to 1.5% of the volume of the oil, when this latter is continuously purified.

It is well to state, however, that the nature of

Courtesy of The DeLaval Separator Company
Fig. 6—Showing the details of a DeLaval Oil Purifier, and also the amount of dirt, plus carbon, developed and removed from an oiling system in one day of operation.

the operating conditions, the original degree of refinement of the oil and the conditions of burning, as noted above, must be considered. Obviously, lower engine temperatures with a

*"Service Characteristics of Diesel-Engine Lubricating Oils," by A. E. Flowers and M. A. Dietrich, presented before the Annual Meeting of the American Society of Mechanical Engineers, 1929.

sufficient volume of highly refined lubricating oil to enable not too rapid circulation, can be expected to result in less sludge and carbon residue development than where the oil is subjected to high temperatures, rapid circulation and more or less oxidation.
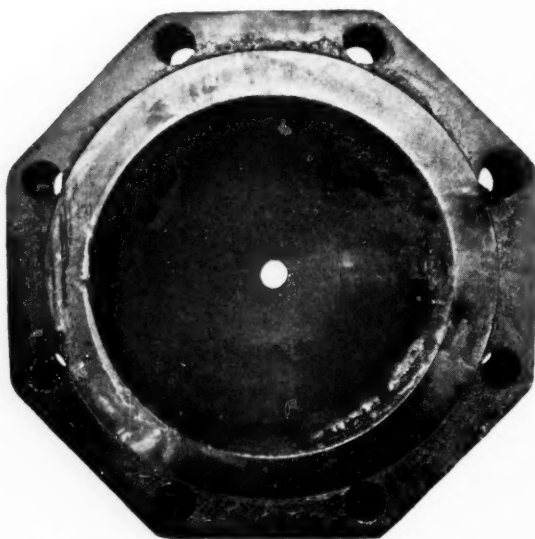

Fig. 7—Showing the crank end view of the combustion chamber of an oil engine, and the extent to which carbon accumulations may develop if too heavy an oil fuel is used or break-down occurs in the lubricating oils.

Diesel Engine Air Compressor Requirements

In view of the fact that in the Diesel the air compressor can be regarded as the heart of the engine, particularly due to the part it plays in bringing about combustion, it will be extremely important to note the effect which carbon deposits may have upon the efficiency of operation of such a compressor.

The air compressor as usually installed in higher powered Diesel engines will generally have either three or four stages, and will be equipped with suitable intercoolers. The compression of air to pressures in the neighborhood of 1,000 pounds will of course develop a considerable amount of heat; it is the function of the intercoolers to reduce this heat and thereby keep cylinder temperatures down thus minimizing the extent of oil vaporization. This is, of course, in the interests of safety, for otherwise accumulations of dust and carbonaceous matter in the intercoolers, etc., might easily so restrict the air passages as to increase the velocity and consequently the frictional temperature of the air to a dangerous extent.

Deposits of Dirt and Carbon

While dirty air is perhaps one of the most general causes of such accumulations of foreign matter, we must not forget that an excessive amount of lubricating oil will tend to develop carbonaceous matter which will materially increase the accumulation of deposits.

In addition, an excess of oil fed to the compressor cylinders may bring about leaky valves due to a certain amount of oil becoming carbonized on the latter. All this, of course, leads to a decrease in operating efficiency. For this carbonaceous matter, being relatively sticky in the early stages of its formation, will also tend to adhere to the piston rings, thereby causing them to become inoperative; furthermore, it will tend to destroy the lubricating film and result in scored cylinders.

Unfortunately, there is no oil which will not deposit some carbon; on the other hand, there is a surprising difference in the nature and quantity of this carbon which will be developed by different oils.

Consequently, not only must an oil be most carefully selected, but also, whatever its characteristics, the utmost care should be taken to prevent the use of more oil than is necessary.

In this respect, it is very difficult for some operators to realize that but one or two drops of oil per minute is all that is necessary. This is effectively counteracted in many Diesel air compressors by so designing that the intermediate stage is at the bottom. As a result of such construction there is always a pressure opposing the tendency of the oil to work up into the air space from the lowest cylinder wall where it may be thrown by the crank-pin.

NATURE OF CARBON DEVELOPED IN SERVICE

As has already been stated, carbon is an essential element in the make-up of any petroleum product. It must, however, be present in more or less intimate chemical combination with hydrogen. There is a distinct difference between carbon as it exists in this manner and carbon as it is found in actual operation in the form of coke or carbon residue. In the former instance the complex-hydrocarbons involved have a high degree of oiliness. They have, therefore, proved themselves as most adaptable lubricants. Coke or carbon residue developed as a result of break-down of certain of these hydrocarbons under high temperature, however, has no lubricating value whatsoever. In fact, the resultant material is even a particularly poor grade of carbon. The nature of this latter from a physical point of view will depend upon the base of the crude from which the lubricant has been refined.

As a result, carbon residue as it appears in the operation of the internal combustion engine or the air compressor will be found to vary widely in its degree of hardness and adhesive-

ness. Whatever its residual form, however, it is always important to remember that carbon, as it results from the break-down of any lubricating oil, is not a lubricant and therefore may develop into a decided abrasive and do a considerable amount of damage to bearings.

It may also accumulate around the piston rings in an internal combustion engine and prevent free operation of these elements. The extent to which this latter may occur, or in fact, accumulation of any excessive amount of carbon residue in such an engine, will depend on the base of the crude, as already stated. In this connection it is interesting to note that the more nearly naphthenic base oils have been found to give a carbon residue of a comparatively soft, fluffy nature, which normally can be easily removed by brushing. It is reasonable to presume that carbon of this nature will oftentimes be very largely removed from the automobile engine, for example, by the exhaust before it has a chance to accumulate within the engine.

On the other hand, certain paraffin base oils if not properly refined will develop a carbon residue which will be of a comparatively hard and adhesive nature. The experiments of Marley, Livingstone and Gruse already referred to are particularly interesting in this regard.

INDICATIONS OF CARBON RESIDUE DEVELOPMENT

In concluding this study of the development of carbon residue and the detrimental effects which it may have upon the lubricating ability of an oil, as well as the operating efficiency of certain types of machinery, it will be well to note those external indications which may be taken as a rough guide as to the development and accumulation of such residue.

The Automotive Engine

In the automotive engine the development and formation of carbon residue, especially within the combustion chamber, may be indicated by a "knocking" or loss of power. To the experienced automotive engineer there are a number of types of knocks, depending upon the condition of the engine, the advancement of the spark, the extent to which timing is right, or the degree to which proper cooling is attained.

"Knocking" as a result of carbon, however, may have a decided tone. Furthermore, it will be most evident when the engine is subjected to heavy loads, as for example in driving over long or steep hills.

The Air Compressor

In air compressor service accumulation of carbon may give rise to improper cooling of the air as it passes through the compressor, intercoolers or aftercooler, or to over-heating in certain of the piping. Accumulation of carbon

Fig. 8—The above illustration indicates how carbon accumulations may interfere with free operation of piston rings. Note also the extent to which carbon has developed on the piston head.

residue deposits in the intercoolers or aftercoolers, or in the valve passages or pipe connections, such as bends, may lead to restriction of the openings through which the compressed air must pass. By restricting such openings back pressure will be built up to such an extent as to, perhaps, bring about explosions.

The Diesel Engine

Accumulation of carbon deposits in the Diesel engine will be primarily indicated by loss of power, just as holds true in any other type of internal combustion engine.

In the Diesel engine, however, there is not the same tendency to develop knocking, due to the manner in which the fuel is burned. As a result, it will be essential for the operator to pay more attention to the power out-put.

This, of course, is more easily accomplished in connection with such an engine, in view of the fact that it is stationary and therefore more readily adapted to the installation of power measuring instruments. In the automotive type of engine, for example, power out-put can only be accurately measured by locating the engine on a test block.

Bearings

There are certain types of bearings wherein accumulation of carbon residue, brought about by abnormally high operating temperatures,

may also seriously impair lubrication. Typical examples of the above will be the trunnion bearings, used in connection with kiln operation in the cement industry, the bearings adjacent to the rolls in the steel industry, and the steam heated dryer bearings in the textile trade. It is important to remember, in connection with any of the above type of bearings, or any bearings where temperatures may run in the neighborhood of 250 degrees Fahr. or above, that a certain amount of break-down of virtually any type of lubricating oil will occur, by reason of the process of partial distillation and oxidation which is brought about by the constant heat involved.

This will tend to remove the more volatile constituents, leaving more or less residue, according to the nature of the original oil and its manner of refinement. Higher viscosity lubricants which may be of blended or residual nature will develop more carbon residue than lubricants which are straight distilled products.

It is interesting to note that the actual carbon residue content of certain steam cylinder oils, by means of the Conradson method already mentioned, will show as high as 6% to 8% carbon. There are certain types of distilled lubricants, on the other hand, which will show but a fraction of 1% of carbon residue deposit by the same method of test.

In studying a problem of high temperature bearing lubrication, it is of considerable importance to give thought to the extent to which development and accumulation of carbon residue deposits may impair lubrication. Too often will an operator decide that in view of the temperature involved he should choose the

heaviest grade of oil available, with only the idea in mind that he must have adequate operating body or viscosity at the prevailing temperature.

Viscosity or body is of decided importance but, in view of the fact that under normal

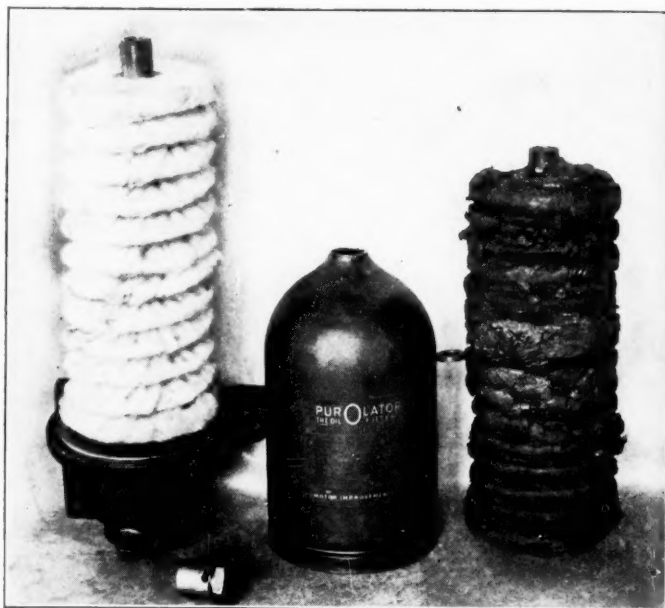*Courtesy of Motor Improvements, Inc.*

Fig. 9—Showing detail of a PurOlator type of oil filter, with the element removed. View of cartridge at the right will illustrate the amount of impurities, including carbon residue, developed in this instance after about 500 hours of running a tractor.

operating conditions research has proven that bearings can be run on an extremely light bodied oil, it would seem that more attention should be given to the matter of possible carbon residue development and the extent to which it might ultimately prevent circulation of lubricant to such a degree as to actually lead to the bearings being burned out, due to lack of lubrication.